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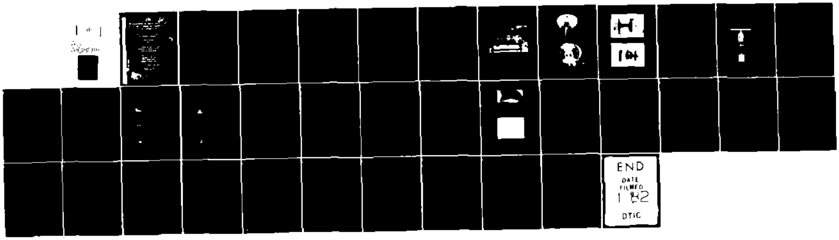

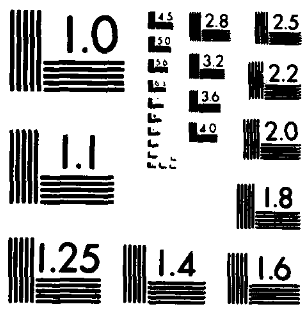

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MECHANISMS OF SMOKE REDUCTION IN THE HIGH-PRESSURE COMBUSTION OF EMULSIFIED FUELS

AD A108018

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Atomization	Drop Sizing	Lasers
Combustion	Drops	Measuring Instruments
Combustors	Emulsified Fuels	Smoke
	Evaporation	

20 ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents progress made during the first year of a three-year study of the atomization and evaporation characteristics of emulsified and alternative fuels in model gas turbine engines. A significant part of this effort involves the development of spray drop-size diagnostics suitable for use in a combustion environment.

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20. ABSTRACT (CONT'D)

A disc-in-duct combustor with a pipe I.D. of 15.04 cm ~~(5.92")~~ and a disc O.D. of 7.19 cm ~~(2.83")~~ has been constructed and operated. A significant amount of optical access is available through 3" x 4" quartz windows.

A Delavan 5.0 gallon per hour 45° cone angle hollow-cone nozzle has been completely characterized at atmospheric conditions on calibration fluid, Jet-A, a Jet-A/20% water macroemulsion, and a Jet-A/20% water microemulsion. Variations of drop size along the nozzle axis and radially outward have been documented.

Modifications to the drop-sizing laser diffraction equipment to permit combustor measurements are described. Some preliminary data for a comparison of atomization of a neat fuel and a macroemulsion fuel when sprayed in high temperature/pressure air are presented.

Recommendations are given for the coming year including further measurements in high temperature/pressure noncombusting air followed by measurements in an operating combustor.

A

MECHANISMS OF SMOKE REDUCTION IN THE HIGH PRESSURE COMBUSTION OF EMULSIFIED FUELS; VOL. I: CONSTRUCTION OF APPARATUS AND PRELIMINARY EXPERIMENTS

INTRODUCTION AND BACKGROUND

High quality petroleum derived fuels are not as widely available as they were in the past. Future fuels derived from petroleum and non-petroleum sources such as coal and shale-oil will tend to be lower in hydrogen content and more viscous with more residual components. These fuels will be more difficult to atomize effectively and will tend to produce more soot during combustion. The purpose of this contract is to conduct fundamental research which addresses two separate aspects of the problems associated with atomization and burning of lower quality fuels. The first aspect is the experimental study of atomization and evaporation of water/oil emulsified fuel sprays in a real combustion environment, with a specific effort to verify the proposed "microexplosion" phenomena. The second goal is to examine the atomization and evaporation of "out-of-spec" fuels which are too viscous or non-volatile to meet the standard fuel specifications for gas turbine combustion. Both of these goals will require the develoment of experimental techniques not presently available to study drop-size distributions of fuel sprays in combusting systems. This report covers progress made during the first year of a three year effort to study atomization in combustors.

The first aspect of the atomization problem deals with the study of emulsified fuels. It has been shown (Refs. 1 and 2) that the increased soot formation resulting from combustion of low hydrogen content fuels can be somewhat offset by mixing water or alcohol with the fuel. Several explanations have been offered to explain this soot-reduction phenomena. These include: (a) better atomization of the emulsified fuel due to "microexplosions" caused by superheating and violent boiling of interior water micro-droplets; (b) a change in the chemical kinetics leading to soot production due to the increased OH or the increase in H/C ratio; (c) the reduction of liquid-phase pyrolysis processes due to lower drop temperatures

resulting from the lower boiling point of water; (d) the reduction of gas-phase pyrolysis processes due to the lower flame temperature from either strictly dilution effects or other chemical processes. One of the goals of this contract is to develop techniques to verify the existence of microexplosions in real combustion systems. Microexplosions have been observed for very large emulsified drops burning in quiescent atmospheres, but no direct measurements have been successfully performed on realistic sprays in turbulent air. Some of the observed microexplosion phenomena have been criticized as unrealistic for several reasons: nucleation introduced by the supporting wire; the large size of the drops (when compared with real spray size distributions); and the lack of high aerodynamic shear forces which promote internal mixing and reduce the possibilities for microexplosions. The purpose of the first part of this program is to develop methods to examine the behavior of sprays of emulsified fuels in a more realistic combustion environment.

The second part of this program involves a study of the atomization and evaporation of alternative fuels, which generally will be more difficult to atomize and evaporate when compared to present-day petroleum-based fuels. Some correlations exist for predicting the change in spray quality for small variations in fuel properties, and some models have been developed for fuel spray evaporation in combustors, but experimental data are lacking to verify these models and extend them to alternative fuels. The same experimental techniques developed for the first part of the program will be used for the second part.

EXPERIMENTAL APPARATUS

Three principal pieces of experimental apparatus have been assembled or purchased for this program. They are the disc-in-duct combustor, the laser diffraction particle sizing apparatus, and the pulsed high-power Nd:YAG laser.

Disc-in-Duct Combustor

A combustor which combines a turbulent recirculating aerodynamic flow pattern similar to a gas turbine engine with a considerable amount of optical access needed for laser spray diagnostics has been designed, constructed, and tested. It burns with stable flames over a range of conditions and fuel/air ratios, but currently suffers from some window degradation as discussed below.

The combustor design selected is a disc-in-duct type used by Mellor and co-workers at Purdue and others. The aerodynamics for this design are fairly well characterized. The combustor consists of a 6" diameter pipe with a coaxial circular disc having an area of 1/3 of the internal pipe diameter. The fuel nozzle is centered in the disc and is flush with the surface. The igniter is a high-voltage spark plug type and is also mounted on the disc. This location for the igniter is convenient but introduces an asymmetry to the flow around the disc. The overall combustor is shown in Figure 1 and the details of the disc in Figures 2 and 3. Large windows were desired for maximum optical access but these do disturb the symmetry of the flow field. The windows selected are 3" x 4" x 1/2" quartz, and the inside of the combustor was machined to provide a transition region between the cylindrical combustor walls and the flat window surfaces as shown in Figure 4. The position of the disc in the combustor is shown in Figure 5.

The air supply system provides a flow of unvitiated air at rates up to 1.1 kg/sec (2.5 lbm/sec); pressures to 16 atm (1620 kPa) and temperatures to 1090K (1500°F) are possible at all flow rates. Air and fuel flow rates are

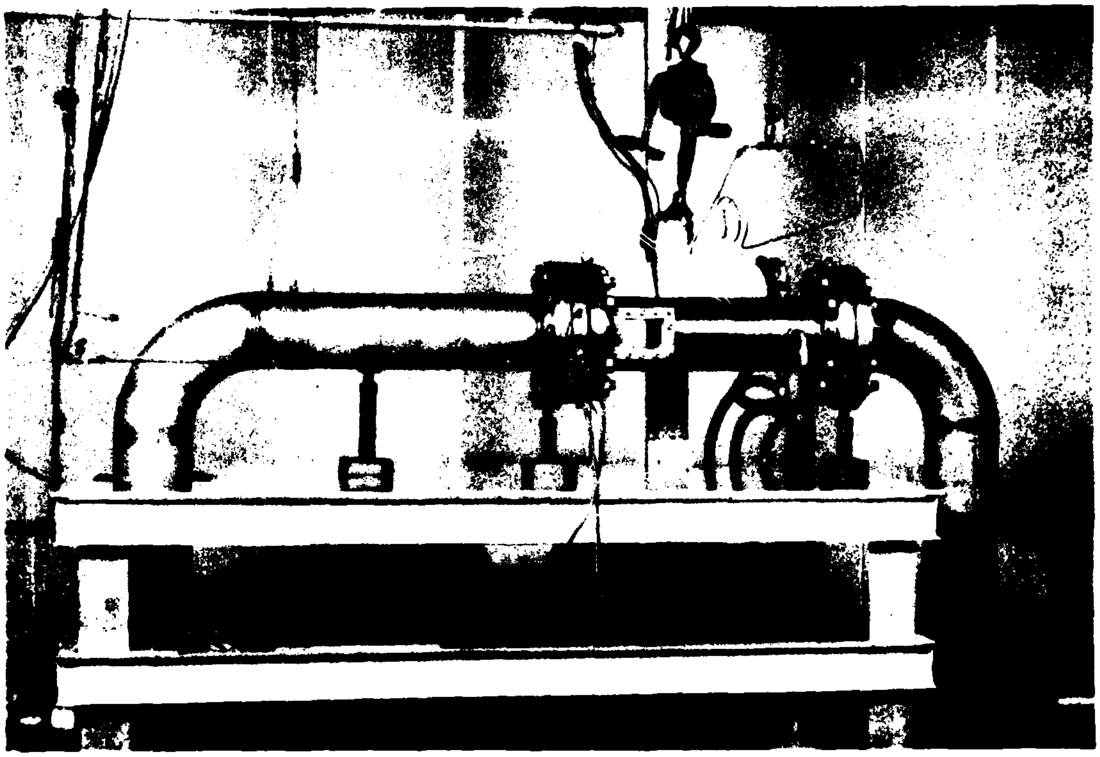

FIG. 1 OVERALL VIEW, DISK-IN-DUCT COMBUSTOR

FIG. 2 DETAILS OF DISC CONSTRUCTION

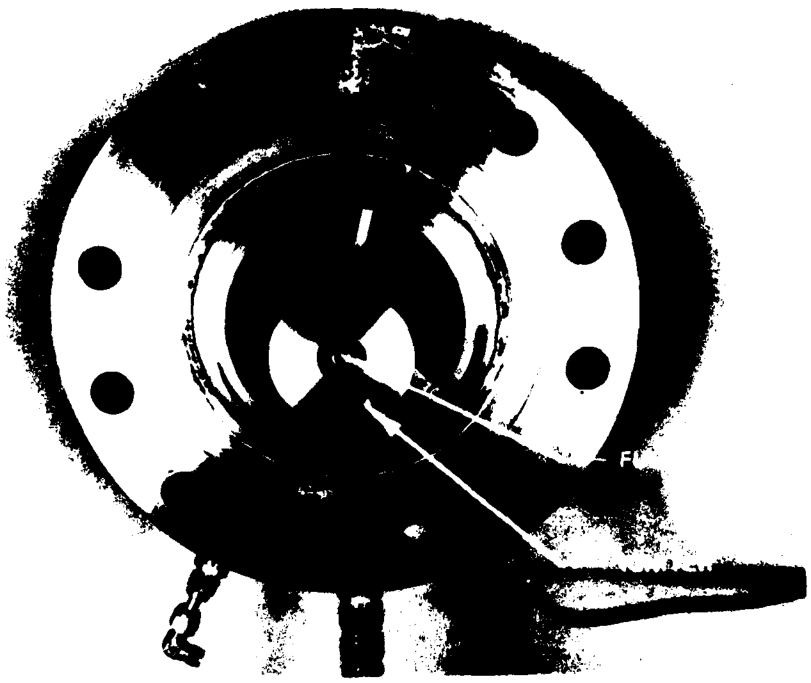

FIG. 3 DISC AND CENTERING FLANGE

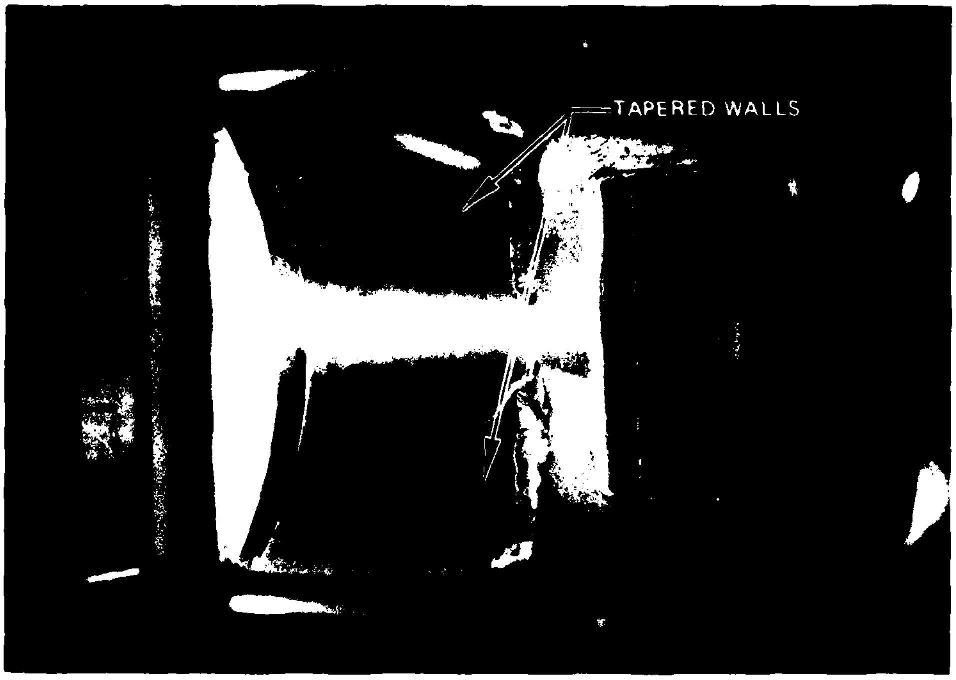

FIG. 4 INSIDE OF COMBUSTOR SHOWING WINDOW TRANSITION REGION

FIG. 5 DISC IN PLACE IN COMBUSTOR

monitored with turbine flow meters, and the combustor is instrumented with several thermocouples to monitor appropriate temperatures. A problem has been encountered concerning the cleanliness of the air from the air factory. Even with no fuel spray there appear to be drops in the air supply, and it is presumed that these are due to oil carry-over from the two compressors. Filters have been ordered which should alleviate this problem.

Up to fifty sensors on the combustor may be monitored using a scanner and Hewlett-Packard 9820 programmable calculator. The calculator handles all of the data reduction and any necessary calculations. The resulting data is then output in one of three ways:

1. It can be put on a printer with any appropriate alphanumeric titles and column headings, as shown in Table 1.

2. It can be output graphically on an X-Y plotter.

3. It can be stored on magnetic tape for further reduction at a later time.

A complete set of exhaust emissions instrumentation is also available.

Drop Size Analyzer

Equipment Description - A laser diffraction instrument called the Malvern Model 2200 Droplet and Spray Particle Sizer has been purchased to form the basis of the spray analysis equipment. The principle of operation is shown in Figure 6 and explained as follows. When a collimated beam of coherent monochromatic light falls on a droplet, a diffraction pattern is formed whereby some of the light is deflected at an angle dependent upon the size of the droplet. Small particles deflect light at higher angles than large particles. If a lens is placed in the light path behind the droplet,

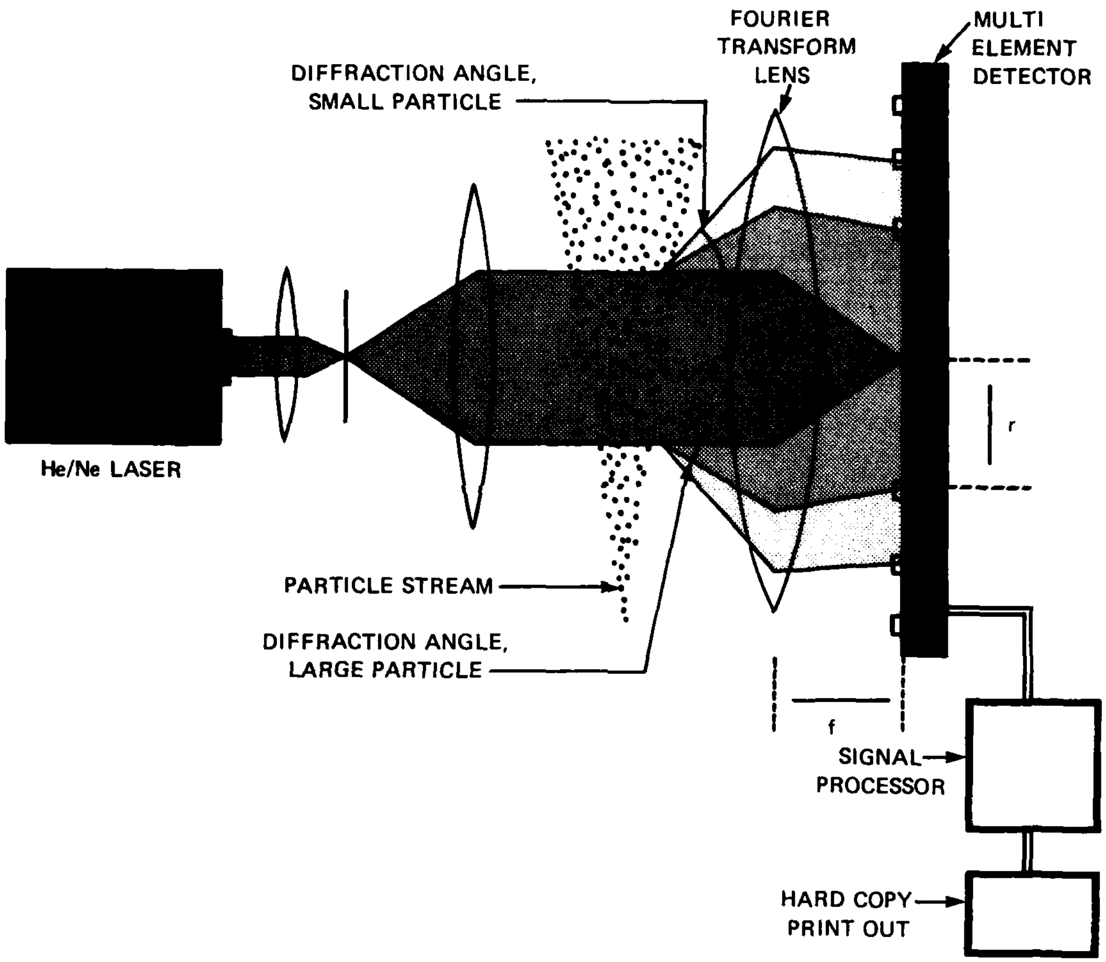

FIGURE 6. SCHEMATIC OF PARTICLE SIZER

TABLE I

U.S. ARMY FUELS & LUBRICANTS RESEARCH LABORATORY
TURBINE-FUELS RESEARCH COMBUSTOR LAB

DISC-IN-DUCT COMBUSTOR
GENERAL COMBUSTOR OPERATING CONDITIONS 2: 0 11/13 81

BIP....BURNER INLET PRESSURE,PSIA
BIT....BURNER INLET TEMPERATURE,F
WA.....AIR FLOW RATE,LBM/SEC
WF.....FUEL FLOW RATE,LBM/MIN
F/A....FUEL/AIR RATIO
VREF...COLD FLOW REFERENCE VELOCITY, FT/SEC
H I....HEAT INPUT, BTU/LBM AIR
ET.....EXHAUST TEMPERATURES, DEG F

BIP	BIT	WA	WF	F/A	VREF	H	ET-1	ET-2	ET-3	ET-4
72.00	400.0	1.850	.450	.004	200.0	100.0				

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15.30	87.4	.123	1.199	.162	18.5	3038.6	86	87	86	87
15.30	84.0	.051	1.208	.392	7.6	7353.1	81	83	82	82
15.30	87.0	.052	1.208	.391	7.7	7332.5	86	87	87	87
15.30	83.1	.051	1.208	.392	7.6	7343.7	82	82	82	82
15.30	87.0	.051	1.209	.392	7.7	7352.5	85	86	85	84
15.30	86.6	.051	1.208	.393	7.7	7379.0	85	86	85	85
15.30	82.7	.051	1.208	.392	7.6	7355.0	81	81	81	81
15.20	82.7	.051	1.208	.393	7.7	7377.1	81	82	82	82
15.20	82.7	.051	1.208	.394	7.7	7383.0	83	83	84	83
15.20	84.4	.051	1.208	.396	7.6	7418.2	84	84	85	85

and a detector is placed at the focal point of the lens, then light not diffracted by the droplet is brought to focus at a point on the axis. Light diffracted by the particle will be concentrated concentrically at a distance from the axis, this distance being a direct function of the droplet diameter. If droplets of different diameter are sampled in the beam then a series of concentric light rings will be generated at various radii, each being a function of a particular droplet size. Since the concentric rings are obtained from parallel rays of light it is termed a Fraunhofer Diffraction pattern. For any group of droplets, their combined diffraction pattern is uniquely related to their particle size, and is independent of droplet motion or position.

Light energy in the droplet diffraction pattern is sampled by a large-scale solid-state detector which consists of 30 concentric rings, each ring being most sensitive to one particular droplet diameter. The electrical output from the rings is analyzed by a microcomputer. A set of three lenses is used to cover the drop size range from 1 to 1800 micrometers (microns).

Data Reduction Computer Programs - The conversion of the light energy distribution into a drop-size distribution is a non-trival problem. Three methods or options are available which are of interest for spray analysis. The first two methods assume a distribution for the volume fraction of drops to correspond to an analytic function which is characterized by two variables - a size parameter and a width of distribution parameter. These two functions are the Rosin-Rammler distribution and the log normal distribution, which have been shown empirically to be representative of many classes of sprays. Values are assumed for the two parameters which define either of the distributions, the corresponding light energy distribution is calculated, and the difference between the calculated and measured light distribution is determined as a least-square error. An iteration scheme is used to minimize this error. The third method of the light-to-drop-size-distribution techniques is called the model independent program which takes the 15 independent values for light intensity (after pairing up detector

rings) and calculates the volume fraction in 15 different size classes. This last technique allows for an examination of bimodal distributions, but is also much more sensitive to noise errors in the measurement. Another two-parameter distribution, the normal distribution, is available but has not been used for spray analysis.

The Rosin-Rammler distribution is the most commonly used distribution for sprays and is a cumulative oversize weight (volume) distribution

$$R = \exp\left(-(d/X)^N\right)$$

where R represents the normalized weight (volume) above d. The size parameter X represents that point where R = 1/e = .368. The character of the distribution is dependent not only on the average size but also on the width parameter N. Typical hollow cone sprays show N values from 1 to 5 with the higher values found in analyzing the edge of the spray. It can be seen from Figure 7 that the characteristics change dramatically for constant X and variations of N from 1 to 5. For X = 70, an N value of about 40 is necessary to achieve a "monodisperse" spray with almost all of the volume distribution in a 10 μm band. An important observation from Figure 7 is that typical sprays show a significant population over a dynamic range of diameters of 15:1, and since evaporation phenomena are proportional to d^2, explanations of spray phenomena in terms of monodisperse sprays are too simplistic to be applicable to real sprays.

The log normal distribution is another skewed distribution similar to the Rosin-Rammler but with longer tails. It defines the weight (volume) distribution to be normal in the space of log particle size, and is obtained from the normal distribution by replacing d with log d. The weight (volume) frequency distribution is

$$I_d = \frac{1}{\ln N \sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln d - \ln X}{\ln N}\right)^2\right]$$

The parameter X is the geometric mean and N is the geometric standard deviation.

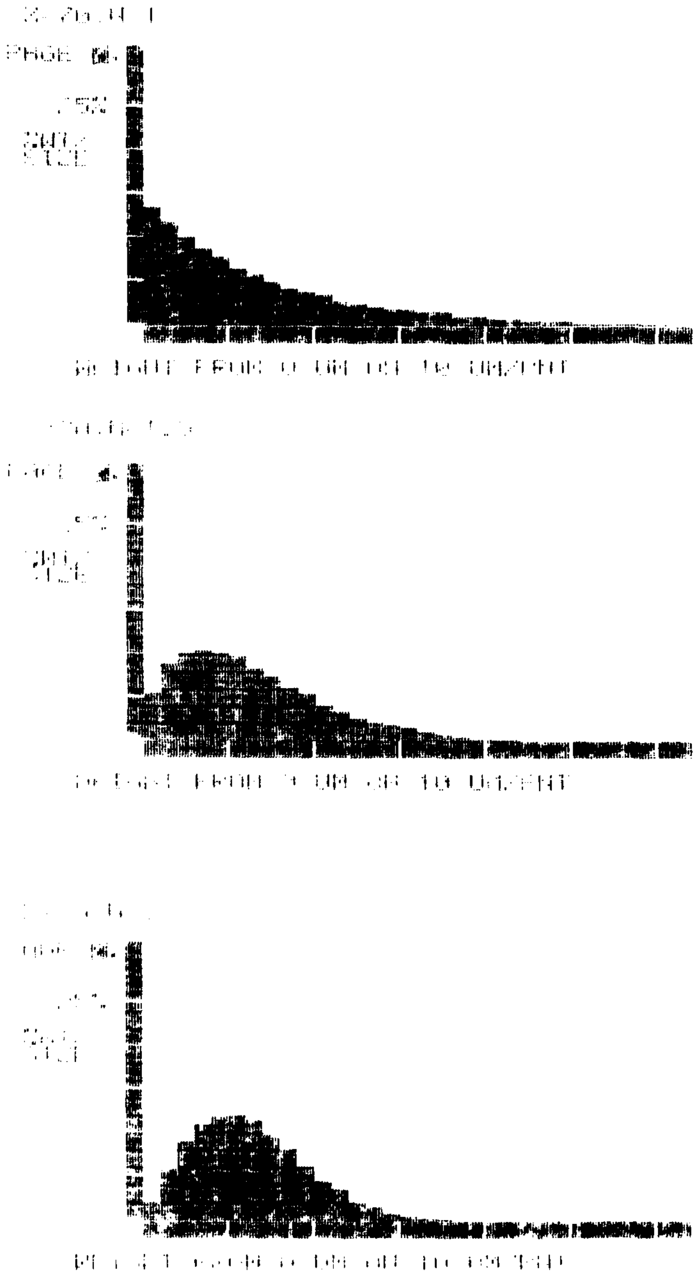
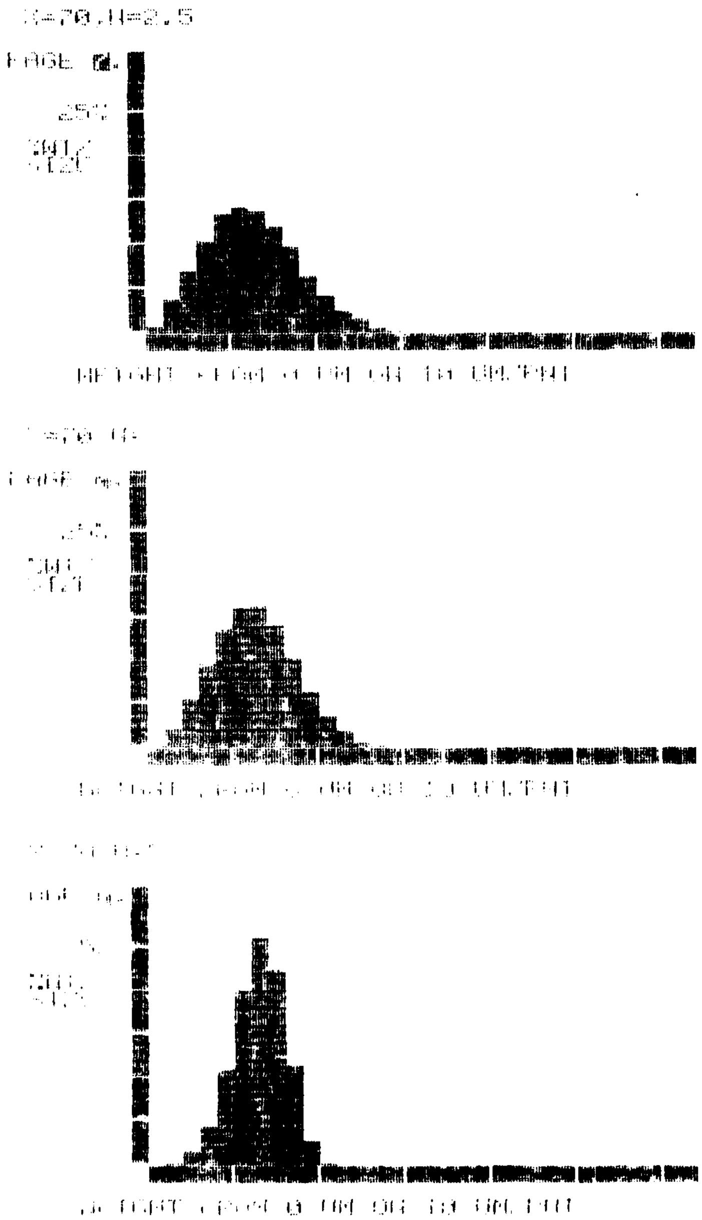


FIGURE 7. COMPARISON OF DROP SIZE DISTRIBUTIONS FOR CONSTANT X BAR BUT VARYING WIDTH PARAMETER N.



(Continued)
FIGURE 7. COMPARISON OF DROP SIZE DISTRIBUTIONS FOR CONSTANT X BAR BUT VARYING WIDTH PARAMETER N.

Guidelines In Use of Malvern - There are some aspects of the operational characteristics of the Malvern which are important for this program and are not adequately covered in the manual. First, there is a maximum distance between the lens and the far extremes of the spray which must be observed or vignetting will occur, which results in a loss of signal to the outer rings of the sample and a biasing of the size distribution towards the larger drops. Geometrical optical considerations indicate the maximum distance X between the spray and the lens is,

$$X = f\left(\frac{D_l}{2} - \frac{D_b}{2}\right) \Big/ \frac{D_d}{2}$$

where f is the focal length of the lens, D_l is the diameter of the lens, D_b is the laser beam diameter, and D_d is the diameter of the outermost detector ring used. Using the data shown in Table II, the maximum distances and maximum acceptance angles for all three lenses are shown in Table II. The maximum distance of 55 mm for the 63 mm focal length lens makes it unacceptable for combustor measurements, and even the 100 mm focal length lens would be difficult to use. Fortunately, the 300 mm lens appears to cover a range of drop sizes (6 μm to 560 μm) which is adequate for the sprays to be investigated.

The windows must be kept clean and free of scratches to be used in the light scattering experiment. This is one of the fundamental limitations to application of this technique to combustors. Careful window design must be used to limit contamination and increase time between cleaning.

Modifications to Light Scattering Equipment for Combustor Measurements - One of the most crucial parts of this program is the design of modifications to the light scattering equipment for use with the combustor. Three problems are of immediate concern. First, as already mentioned, the windows must be kept clean. Second, the laser signal must be enhanced by several orders of

TABLE II

Detector diameter: 28.6 mm

Laser beam diameter: 9. mm

Lens data

Focal length (mm)	Diameter (mm)	X (mm)	θmax (degrees)
63	34	55	12.8
100	44	122	8.1
300	41	336	2.7

magnitude relative to the flame radiation so that it is detectable. Third, the density gradients caused by thermal gradients will steer the beam and force it to scintillate causing the undiffracted beam to be steered off the central detector and adding noise to the signal. Proper design and modifications will be used to minimize the first two problems and combustor conditions will be selected to minimize the third.

A combination of several things have or will be used to enhance the laser signal relative to the background radiation from the flame. An optical interference filter has been used to limit radiation seen by the detector to the wavelengths centered about that of the laser. However, caution must be exercised in the selection of the bandwidth. By design, the light diffracted by the droplets enters the lens at some angle to the optical axis, with the maximum angle for each of the three lenses shown in Table II. But the band-pass of interference filters is sensitive to the angle of incidence, being shifted to shorter wavelengths as the angle of incidence increases. Thus a very narrow band-pass filter centered at the laser wavelength would pass radiation near the axis but would discriminate against radiation bound for the outer detector rings (i.e., higher incidence angle). This would result in a drop size distribution weighted toward the larger drops. Using the maximum angles given in Table II, it can be calculated that reasonable minimum filter bandwidths for the three lenses would be 3 nm for the 300 mm f lens, 10 nm for the 100 mm f lens, and 20 nm for the 63 mm f lens.

Two interference filters of 3 nm bandwidth have been purchased, one for the HeNe laser at 632.8 nm and the other for the Nd:YAG second harmonic at 532 nm. Used with the HeNe laser, this filter reduces the interfering flame radiation by several orders of magnitude, but the outer detector rings are still saturated with flame radiation, as expected from previous calculations. In addition, the filter causes an undesirable increase in background signal.

A light baffle has been designed to geometrically limit radiation falling on the detector to that originating in the region where the laser beam intercepts the spray.

Both the optical filter and the light baffle will help to discriminate against flame radiation, but additional steps must be taken to get a reasonable signal. Two approaches will be considered. For relatively transparent (low emissivity) flames, it may be sufficient to chop the HeNe laser beam and add either an A.C. amplifier or a phase sensitive detection system to the receiver electronics. For flames of greater emissivity, it will be necessary to use a pulsed high-power Nd:YAG laser with a separate integrate-and-hold amplifier for each of the 30 detector elements. In addition to the interference filter it is necessary to use neutral density filters to reduce the Nd:YAG laser radiation so that the detector is not destroyed. These filters also reduce the flame radiation to a negligible level.

High Resolution Photographic System

A high-resolution photographic system which was developed for another program may be useful in this project. It consists of a high-resolution lens, COM-Nikkor 88 mm focal length f/2, and a Sinar 4" x 5" view camera with extra bellows extension. High resolution holographic-type film is used. The lens is designed for 5:1 image reduction but has been used previously in a reversed direction for 5:1 magnification. It is necessary to use a very high speed strobe (~50 ns) to freeze the fuel sprays, but with sufficient intensity to expose the high resolution film. A pulsed laser is usually required to meet these requirements; the Nd:YAG laser mentioned above frequency-doubled to 532.0 nm with an pulse width of 7 ns and an energy of 60 mJ, has been used for this with success. This system has been used to examine diesel fuel injection processes. An example is shown in Figure 8, and the detail available in the high resolution film is shown in the 50X enlargement in Figure 9.

FIGURE 8. INITIATION OF FUEL INJECTION
SPRAY PENETRATION IS ABOUT 0.6 INCHES OR 1.6 cm.

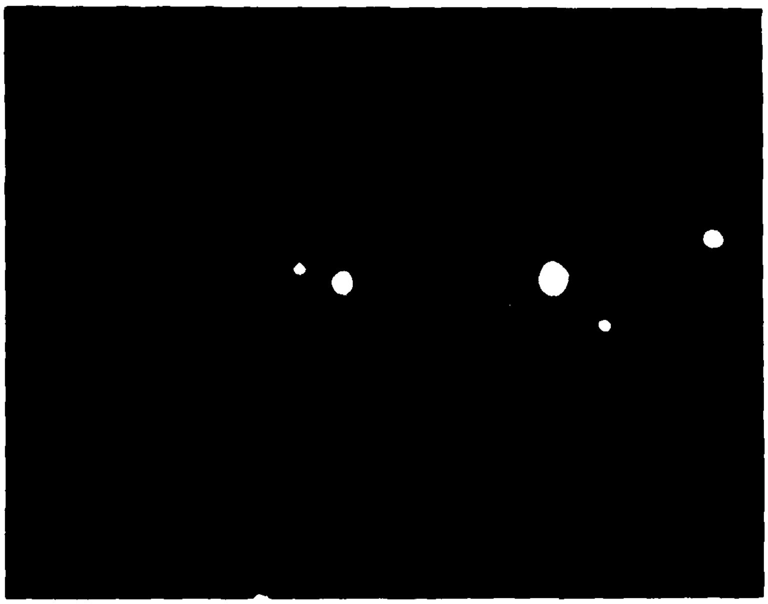


FIGURE 9. HIGH-MAGNIFICATION (250X) PHOTOGRAPH OF FUEL SPRAY
SHOWING DROPLET SIZES FROM 6 TO 20 μm.

EXPERIMENTAL RESULTS

Droplet Size Measurements - Bench Tests

A number of tests have been performed with the Malvern spray analyzer with different nozzles and fluids to determine several things. First the operational characteristics of the analyzer were established. Then the general performance of hollow-cone nozzles was determined including the effects of fluid pressure, viscosity, distance from nozzle face, distance from nozzle axis, etc. In addition, the differences between emulsified fuels, both micro- and macroemulsions, and neat fuels were established at atmospheric temperature and pressure.

It has been established that the droplet sizer and spray apparatus can perform in a very repeatable fashion. Five nozzles nominally rated at 1.50 gallons per hour (gph) at 100 psid (differential pressure) and 80° cone angle were tested twice each at 1000 psid using calibration fluid. Considering the complexity of the problem of spray sizing, the results were quite impressive as shown in Table III. The average difference in Sauter Mean Diameter (SMD) in the repeat runs on a given nozzle was 1.3%, and the standard deviation for the data on all five nozzles was 3.4%. The accuracy is more difficult to establish and tests are continuing to verify the calibration of the unit.

Some general characteristics of hollow cone nozzles have been established. As shown in Figure 10, the SMD rapidly decreases as drops break apart and evaporate over the first 40 to 50 mm (2") of travel and then the SMD increases as the drops slow and breakup terminates and as the small drops evaporate much more quickly than the large drops. In view of the fact that drop lifetime is proportional to the square of the diameter (d^2), it is clear that the smaller drops are evaporating completely forcing the average drop size of the total population larger. The width of the distribution does not change dramatically as a function of the distance from the nozzle face, but does broaden slightly to a maximum at a distance of 40 mm. (Note that the distribution width increases as N decreases.)

TABLE III

COMPARISON OF SAUTER MEAN DIAMETER
OF FIVE DIFFERENT NOZZLES

Nozzle	Sauter Mean Diameter
1	31.1
1	31.2
2	31.3
2	31.6
3	31.0
3	31.7
4	31.1
4	31.0
5	29.1
5	28.3

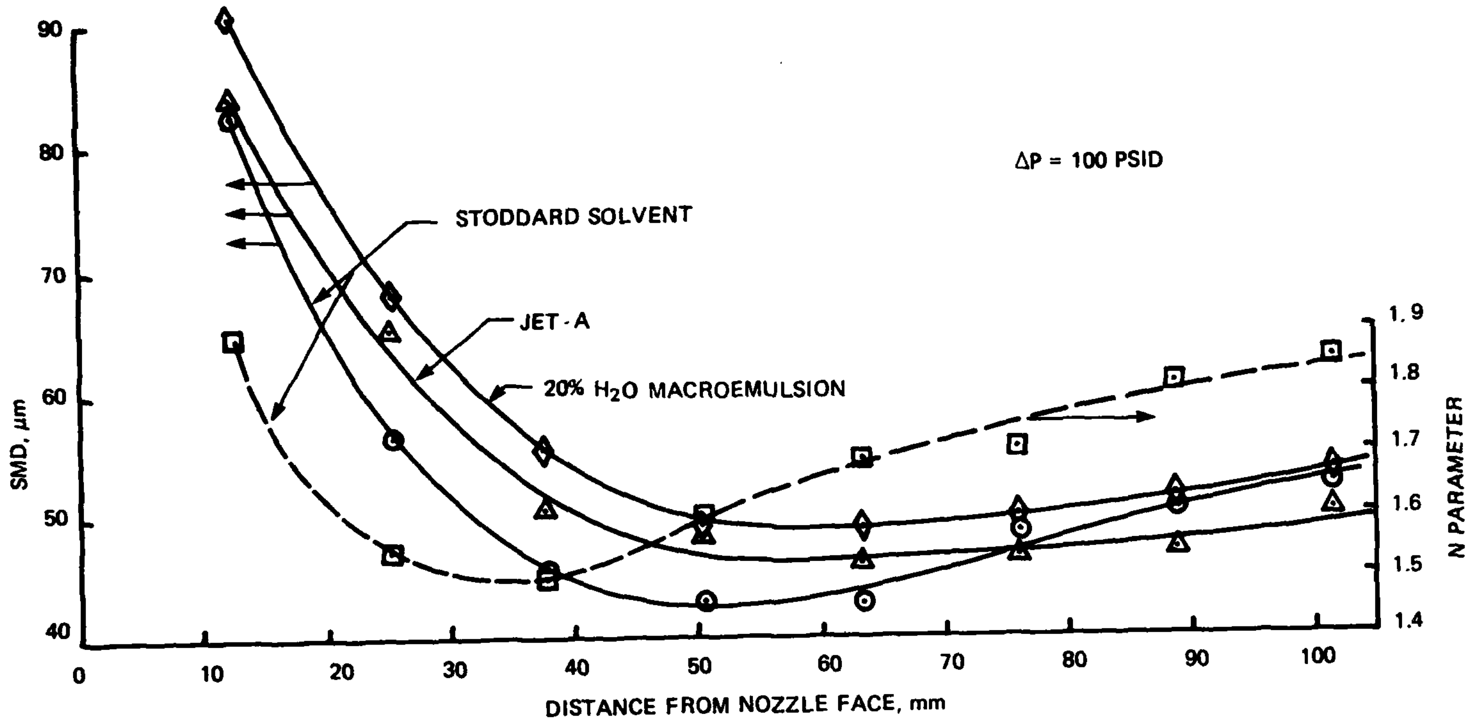


FIGURE 10. EFFECT OF DISTANCE FROM NOZZLE ON SMD; JET-A, H_2O MACROEMULSION AND CALIBRATION FLUID; 5.0 GPH 45° HOLLOW CONE NOZZLE

If drop sizes are examined in a plane perpendicular to the nozzle axis and at a fixed distance from the nozzle face, the spray is quite nonuniform. Because the nozzles examined are of the hollow-cone type, the greatest concentration of drops is in an annulus near the outer extent of the spray. As shown in Figures 11 and 12, the drop sizes are largest in this annulus and drop off slightly at the outer edge of the spray and decrease dramatically toward the center of the spray. The results shown in Figures 11 and 12 are line-of-sight averages so the smaller values towards the nozzle axis include the larger drops in the outer annulus. The width of the distribution is narrow where the line-of-sight includes only the drops in the outer annulus, while along the centerline the distribution width is much broader as expected. A deconvolution scheme has been developed at another laboratory (Ref. 3) to estimate the spatial distribution of drops in an axisymmetric spray from line-of-sight average drop size measurements.

Injection pressure has a significant effect on SMD as shown in Figure 13. An increase in injection pressure from 50 to 200 psid reduces SMD by a factor of more than two, and increasess the width of the distribution simultaneously.

Fuel properties such as viscosity, surface tension, and density affect spray size. Viscosity increases in going from calibration fluid (Stoddard Solvent) to Jet-A to the 20% macroemulsion, and Figures 10 and 13 show the corresponding slight increase in drop size. However, an important conclusion from these atmospheric pressure and temperature tests is that the 20% macroemulsion behaves almost identically with Jet-A so that any large differences in atomization observed in the combustor cannot be attributed to effects in the nozzle, but rather must be due to microexplosions or some other phenomena related to the high temperature/pressure environment.

While the macroemulsion contained 20% water and 2% surfactant, the microemulsion tested was an "extreme-case" mixture containing 20% water, 20% surfactant, and 60% Jet-A and did show significant differences in atomization when compared to the neat Jet-A or calibration fluid. The microemulsion would not atomize well at 100 psid, where the other fuels were tested, and required about 150 psid to achieve a good quality spray. As shown in Figure 14, the drop size characteristics of the microemulsion were different

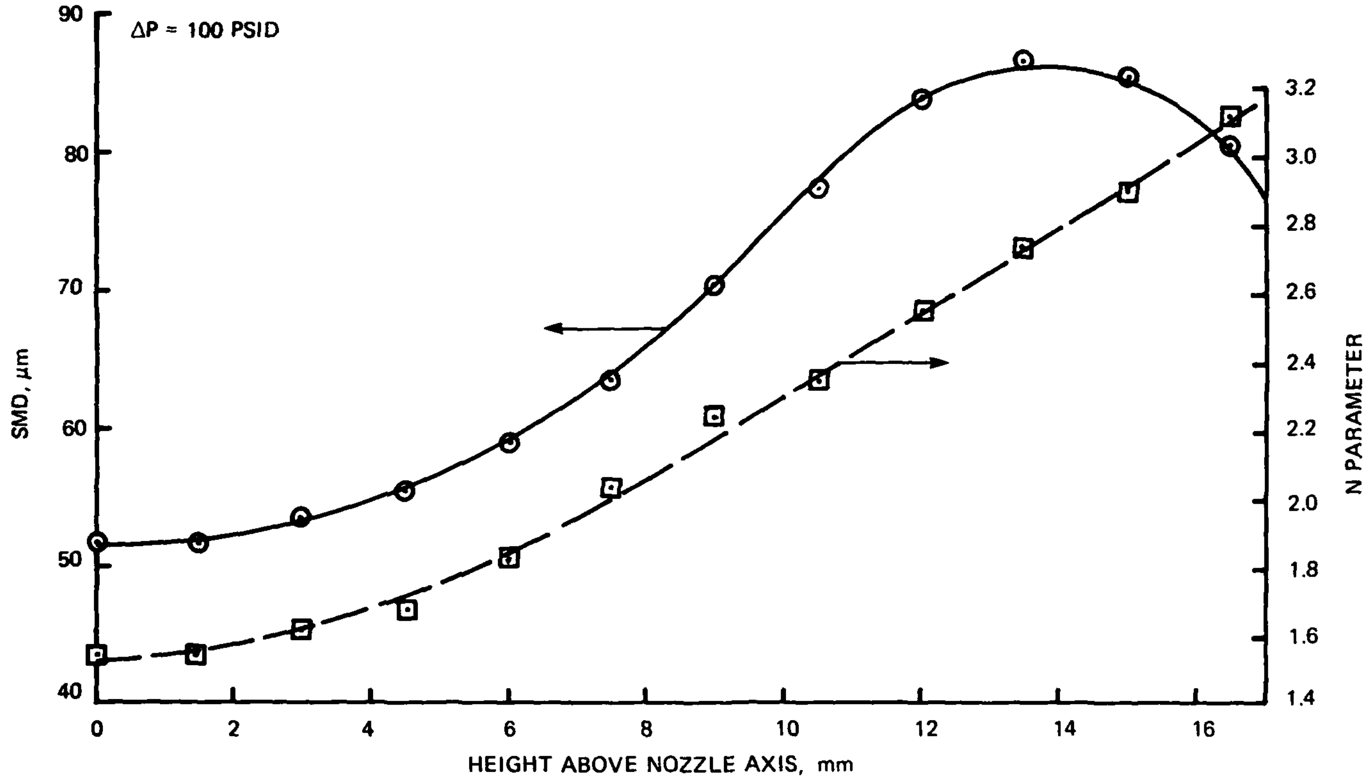


FIGURE 11. SMD AS A FUNCTION OF HEIGHT ABOVE NOZZLE AXIS AT A DISTANCE OF 25.4 mm FROM NOZZLE FACE.

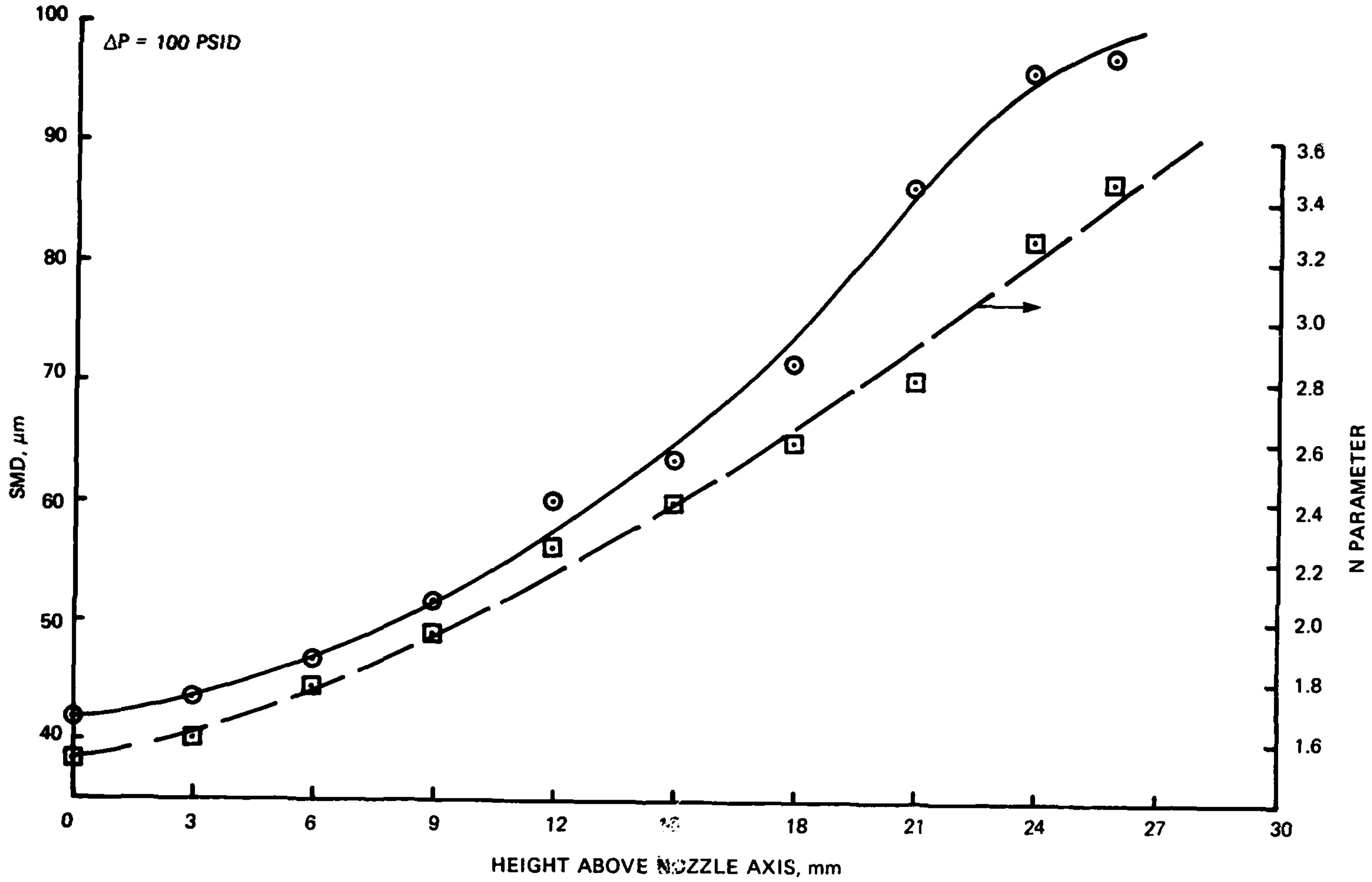


FIGURE 12. SMD AS A FUNCTION OF HEIGHT ABOVE NOZZLE AXIS AT A DISTANCE OF 50.8 mm FROM NOZZLE FACE.

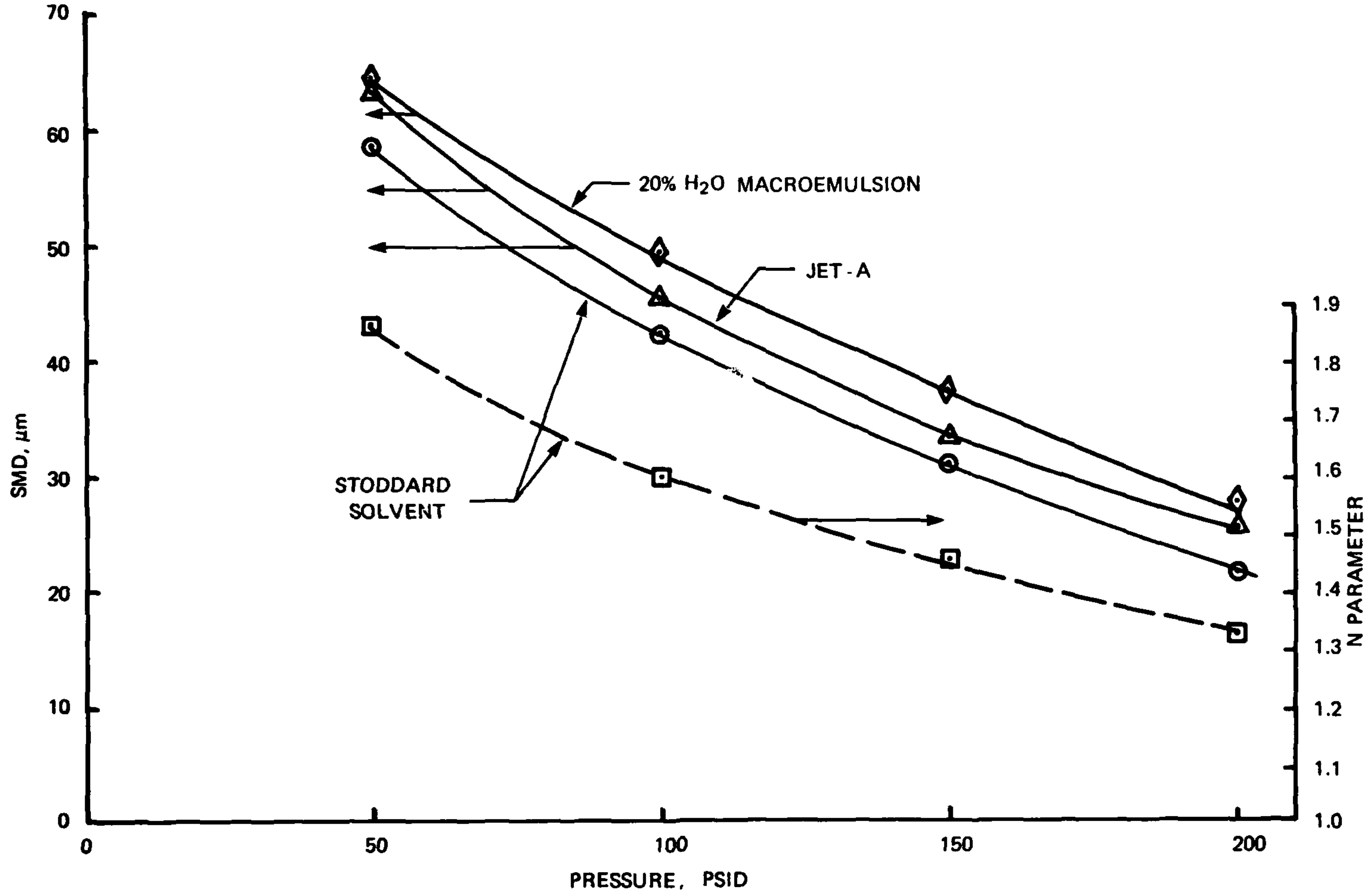


FIGURE 13. EFFECT OF INJECTION PRESSURE ON SMD; JET-A, WATER/JET-A MACROEMULSION, CALIBRATION FLUID.

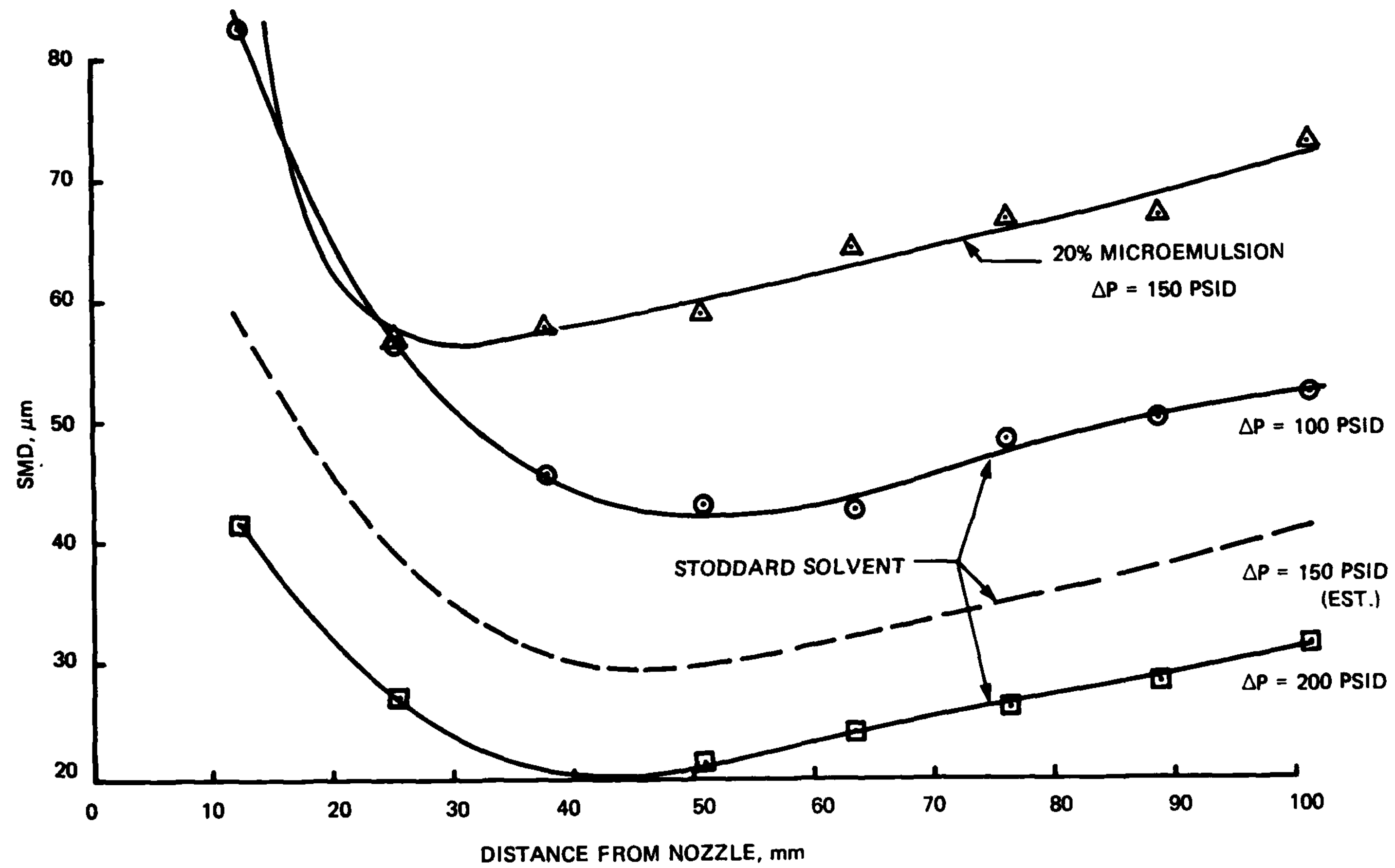


FIGURE 14. EFFECT OF DISTANCE FROM NOZZLE ON SMD; WATER/JET-A MICROEMULSION AND CALIBRATION FLUID.

from the calibration fluid with generally much larger drops due to the high percentage of high-viscosity surfactant. Again, this was an extreme-case microemulsion with a higher fraction of surfactant than is normally used, but the idea was to identify possible differences in atomization with the extremes in fuel properties. Two more-modest microemulsions of 10% water, 6% surfactant, and 84% diesel fuel in a nozzle from a T-63 combustor showed an increase in SMD of only 1% and 12% when compared to the neat fuel. Thus the macroemulsions behave similarly to the neat jet fuels in atmospheric pressure/temperature atomization, and the microemulsions of 10% water/6% surfactant and less will also probably behave like neat fuels.

A multi-variable linear regression analysis computer program is currently being used to correlate drop size with fuel characteristics and injection pressure, but the results are not complete at this time.

Having established the atmospheric pressure/temperature atomization characteristics of Jet-A, one macroemulsion, and one microemulsion, it is now possible to examine their atomization under more realistic elevated pressure/temperature conditions.

Droplet Size Measurements

Preliminary Combustor Tests - Measurements have not been performed in an operating combustor i.e, with combustion, but tests have begun in preheated elevated-pressure air supplied by the air factory at the combustor facility. These tests have been complicated by oil-droplet carryover from the compressors, as discussed earlier. However, one set of test results carried out at elevated air pressure and temperature and 16.3 mm (0.64") from the nozzle face are shown in Figure 15. Within the scatter of the data there is little difference bwtween the 20% macroemulsion and the neat Jet-A except that the macroemulsion drops appear slightly smaller rather than slightly larger as expected.

More extensive tests will be performed in preheated high-pressure air before operating combustor measurements are attempted.

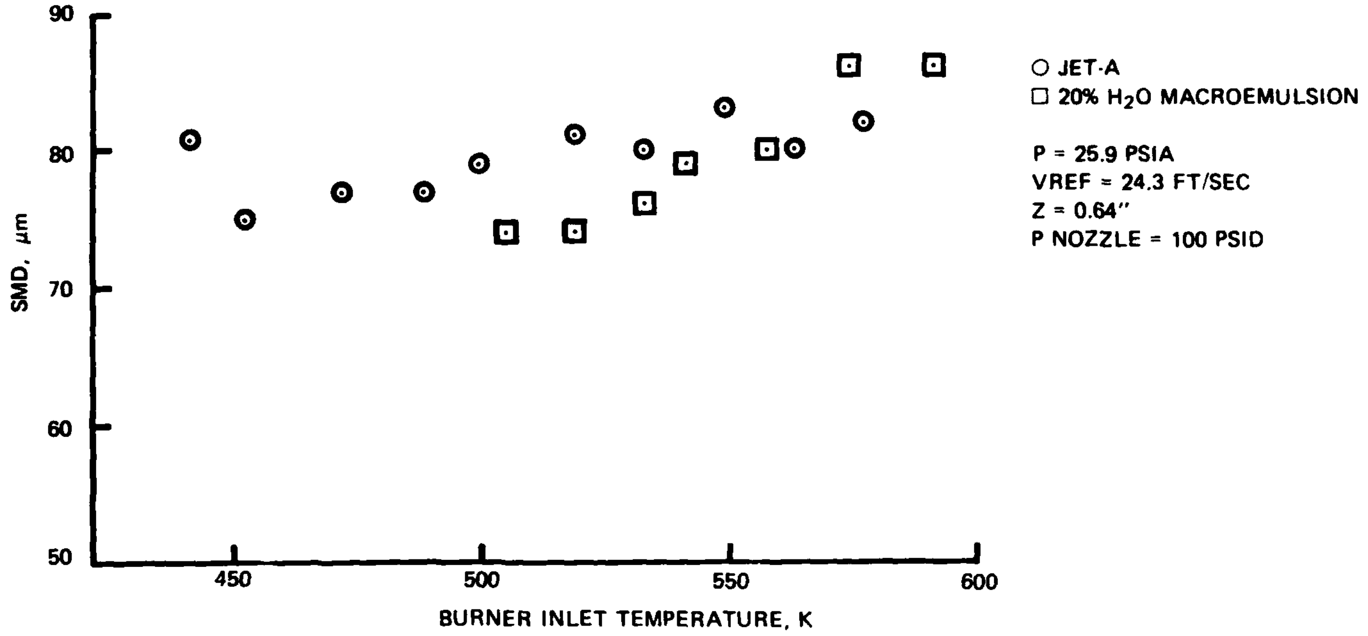


FIGURE 15. COMPARISON OF ATOMIZATION OF EMULSIFIED FUEL AND NEAT JET FUEL IN ELEVATED PRESSURE/TEMPERATURE AIR.

SUMMARY OF FIRST YEAR RESULTS

1. A disc-in-duct combustor which offers a large amount of optical access has been designed, constructed, and operated.

2. A forward diffraction light-scattering drop sizer built by Malvern has been purchased and checked out.

3. The spray drop sizes of four fluids, aircraft fuel system calibration fluid, Jet-A, a 20% water macroemulsion with Jet-A, and a 20% water microemulsion in Jet-A have been examined in detail in a hollow-cone simplex nozzle.

4. Modifications have been made to the particle sizing instrument which should permit measurements in a fairly low-sooting combustion environment.

RECOMMENDATIONS

The objectives for the next year are similar to the original plan, but more detailed plans have been formulated.

1. The oil carryover problem from the compressors in the air factory for the combustor will be fixed so that window problems in experiments without combustion will be alleviated.

2. In order to measure the diffracted laser energy against the background flame radiation, a narrow band-pass optical interference filter has been used along with additional apertures in the optical system. Additional modifications to the electronics and laser system will be used to complete the changes needed to make droplet size measurements in a burning spray. Two approaches will be used in the modifications to the electronics/laser system. First the standard HeNe laser will be used with a mechanical chopper. The electronics will be modified for phase-sensitive detection of the

signal. These modifications may require changes in the machine language code used in the computer which interfaces with the detector electronics. Discussions are currently underway with the instrument manufacturer in England (Malvern) concerning these changes in the computer code, and the phase-sensitive electronics have been designed and constructed. The second approach to discriminating the laser signal against the background flame radiation will utilize the high-power pulsed Nd:YAG laser operating at about 20 pulses per second and appropriate electronics to sample the laser signal when it is present. A gated integrator has been obtained and will be used to check out the interfacting between the detector and the electronics and computer.

3. The properties of emulsified fuels, both macro- and microemulsions, will be examined in more detail. The effects of viscosity, surface tension, and density on atomization at atmospheric pressure/temperature and then at elevated pressure/temperature will be studied.

4. Atomization tests will be conducted with both neat and emulsified fuels in preheated high pressure non-combusting air.

5. Atomization tests will be conducted with burning sprays in the model gas-turbine combustor.

6. The multi-variable linear regression analysis will be used to correlate atomization with fluid properties in the above tests.

7. If time is available, efforts will be made to examine experimental results of spray behavior in light of existing computer models of spray/air interaction in turbulent combustor environments.

ACKNOWLEDGMENTS

We wish to thank Professor J. Swithenbank of Sheffield University for his contributions in developing the diffraction technique for drop sizing and his suggestions on the use of such an instrument for this application. We gladly acknowledge the efforts of Mr. Keith Ellingsworth of the Office of Naval Research in overseeing the technical aspects of this contract. Mr. Harold Simmons and Mr. Barry Weiss of Parker-Hannifin have shared many ideas regarding the operation of the particle-sizing instrument.

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